Biomechanical study of full-contact karate contrasted with boxing

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It is known that boxers suffer a characteristic cumulative brain injury from repeated blows to the head that correlates well with the number of bouts fought. Much less is known about full-contact karate (kickboxing), which is relatively new. In full-contact karate, punches and kicks are actually landed, rather than being focused to culminate just short of an opponent, as practiced in traditional karate. Although a combatant can win on points, the surest means of victory is a knockout. Consequently, fighters strive to land blows to the head.

To investigate the relative force of kicks and punches, a dummy head was mounted 175 cm above the floor (to simulate a 50th-percentile man standing erect) and 125 cm above the floor (to simulate the man in a crouched position) on a universal joint permitting motion about three axes. The mechanism was contrived to provide constant rotational stiffness, and springs provided constant restorative moments about the three axes. The texture of soft tissue was simulated by a mask of visco-elastic foamed materials. Fourteen karate experts punched and kicked the dummy. Accelerometer measurements in the 90- to 120-G range indicated that safety-chops (hand protectors) and safety-kicks (foot padding) did not reduce acceleration of the dummy. Ten-ounce boxing gloves mitigated peak acceleration to some extent. Kicks and punches produced accelerations in the same range.

Violent acceleration of the head by any means produces injury. The authors conclude that, if full-contact karate is widely practiced, cases of kickboxer’s encephalopathy will soon be reported.

KEY WORDS • head injury • boxing • karate

It is now well known that repeated blows to the head produce cumulative brain damage. There is excellent documentation from postmortem examinations in persons dying after single or repeated brain injuries and from serial neuropsychological tests performed at intervals in persons subject to repeated injuries that proves unequivocally that violent acceleration of the skull and its contents results in characteristic patterns of brain injury and a steady decline in the ability to efficiently process information. Injury severity correlates well with the length of a boxing career and the number of bouts fought.

Much less is known about full-contact karate (kickboxing), which is relatively new in North America, than is known about boxing. Professional full-contact karate is a marriage of traditional boxing and karate-style kicks. It differs from traditional karate in that contestants fight in a boxing ring and wear boxing gloves and safety-kick foot padding. In full-contact karate, punches and kicks are actually landed rather than being focused to culminate just short of an opponent as practiced in traditional karate. Although a karateka (combatant) can win on points, the surest means of victory is a knockout. Consequently, fighters strive to land blows to the head.

Violent angular acceleration of the head may occur with punches or kicks. A blow to the chin, especially when a combatant is already partially stunned, produces this effect. To determine whether or not the information published over the years about boxing had application to full-contact karate, a biomechanical study was devised to investigate the relative forces of kicks and punches.

Materials and Methods

Instrumentation

A 50th-percentile Hybrid II dummy head was mounted on a universal joint permitting motion about three orthogonal axes. The two horizontal axes were located 15 cm below the attachment of the “skull,”
corresponding approximately to the cervicothoracic junction. The mechanism was designed to provide constant rotation stiffness over the range of motion for each axis of rotation. The flexion-extension stiffness in the sagittal plane was 0.81 Nm/degree. Side-to-side stiffness to center the head in the coronal plane was 0.54 Nm/degree. Torsional stiffness to center the head about the vertical axis was 0.54 Nm/degree. The “neck” mechanism was contained within a stiff steel column that could be bolted directly through the concrete floor for measurements at a lower height (125 cm from the floor to the top of the head) to simulate a 50th-percentile man in a crouched position. The unit was mounted on a pedestal for a higher level (175 cm from the floor to the vertex), the height of a 50th-percentile man standing erect. The steel column was contained within a 30-cm diameter cardboard tube, and the “neck” mechanism was enclosed within a tube of polyurethane foam to prevent injury to the karate experts who punched and kicked the dummy.

Since the Hybrid dummy does not simulate the viscoelastic energy-absorbing properties of soft tissue, it was fitted with a mask made of 5-cm thick medium-density Temper foam with a cover of 1-cm thick Plastizote to simulate the frictional properties of skin. Accelerometers were mounted at the center of mass of the head, aligned along the sagittal and coronal axes. These were supplied at 10 V direct current. The outputs were fed through differential amplifiers, and a digital storage oscilloscope stored and displayed the two traces in the chopped mode. The time base was triggered from one of the accelerometer signals using a module that enabled data preceding the trigger point to be captured. The sampling rate was 12.8 kHz. Data were stored and analyzed using a microcomputer interfaced to the oscilloscope on the IEEE Bus.

Subject Selection

Fourteen subjects with black belts in karate were involved in the study. These subjects were volunteers selected by one of the authors (K.H.). Each was experienced at both kicking and punching. Their average height was 173 cm (range 153 cm to 179 cm, standard deviation 8 cm). The average weight was 76 kg (range 49 kg to 95 kg, standard deviation 12 kg).

Each karateka was required to strike the dummy in a testing sequence involving 20 different combinations of style, protective wear, and dummy height (Table 1). The combinations were tested in random order. The subjects were encouraged to practice with light blows before attempting to hit the dummy as hard as possible. Following each attempt, the subject was asked if he was satisfied that the attempt represented his maximum force or whether he thought he could do better. If the subject considered that his result was his best effort, then it was stored on magnetic tape for later analysis. If the subject was dissatisfied with his efforts, the result was erased and he was asked to repeat the blow. This sequence was repeated as many times as the subject desired until he was satisfied that the result represented his best effort.

Protective Equipment

All safety equipment used in the testing was new. The 10-ounce boxing gloves were Model IC670, manufactured by International Cougar Athletic Equipment Canada, Inc. The karate-style hand protectors and foot protectors were Macho Punch and Macho Kick, respectively, manufactured by Macho Products.

Test Parameters

Table 1 provides a summary of the blows and equipment tested. Punches were delivered using bare hands, karate-style “safety-chop” hand protectors, and 10-ounce boxing gloves. The kicks were performed with bare feet and when wearing “safety-kicks.” Each punch was delivered to both the side and front of the “head.” The combination of six punches and four kicks was repeated with the “head” positioned at the lower and the higher height to simulate striking a crouching and erect opponent, respectively.

The sagittal and coronal accelerometer outputs were summed to provide the resultant acceleration. The maximum resultant acceleration was determined and used in the statistical analysis. The generalized linear model (GLIM) statistical package was employed.

| TABLE 1 |
| Test series of style, protective wear, and dummy height* |

<table>
<thead>
<tr>
<th>Type of Blow</th>
<th>Hand or Foot Padding</th>
<th>Front of “Head”</th>
<th>Side of “Head”</th>
</tr>
</thead>
<tbody>
<tr>
<td>175 cm (opponent standing erect)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>punch</td>
<td>bare fist</td>
<td>R</td>
<td>B</td>
</tr>
<tr>
<td>safety-chop</td>
<td>R</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>10-oz boxing glove</td>
<td>U</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>kick</td>
<td>bare foot</td>
<td>S</td>
<td>RB</td>
</tr>
<tr>
<td>safety-kick</td>
<td>S</td>
<td>RI</td>
<td></td>
</tr>
<tr>
<td>125 cm (opponent crouching)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>punch</td>
<td>bare fist</td>
<td>R</td>
<td>B</td>
</tr>
<tr>
<td>safety-chop</td>
<td>R</td>
<td>B</td>
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<td>S</td>
<td>RI</td>
<td></td>
</tr>
</tbody>
</table>

* Punches: R = reverse; U = uppercut; B = back fist; H = hook. Kicks: S = sidethrust; RB = roundhouse, striking with ball of foot; RI = roundhouse, striking with instep.
Results

Eleven karateka produced 20 “best effort” tracings each and three produced 16 tracings each, providing 268 oscilloscope tracings for analysis. Figure 1 shows a typical (rather than maximal) acceleration curve caused by a punch to the side of the “head.” Peak acceleration is indicated on the vertical axis with time in milliseconds on the horizontal axis. Peak acceleration in this particular example is 44 G. Figure 2 shows acceleration of the dummy, generated by a kick to the side of the “head” administered by the same subject. Peak acceleration is lower in this case for the kick but acceleration continues for a greater length of time.

When subjects were able to kick the dummy at both the higher and lower heights, the height of the dummy had no effect on the force of blows landed as there was no significant difference between the maximum acceleration generated at the “head” in the lower and in the higher positions \( (p > 0.25) \), regardless of the type of blow (kick or punch). Three karateka were unable to kick the dummy in the higher position. Punches to the side of the “head” using the back of the fist (with or without safety-chop gloves) produced greater peak acceleration on the average than kicks to either the side or the front of the “head.” Punches to the side of the “head” produced greater peak accelerations than punches to the front \( (p < 0.005) \). There was no significant difference between kicks to the side and kicks to the front of the “head” \( (p > 0.1) \). Kicks to the side and front of the “head” produced greater maximum accelerations than punches to the front of the “head” \( (p < 0.025) \). In summary, on the average, for bare or karate-
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style equipment-protected (safety-chop and safety-kick) hand and foot blows, punches to the side of the "head" produced greater peak accelerations than did kicks to the front and side, which in turn produced greater acceleration than did punches to the front of the "head."

Safety-chop karate-style protective handwear did not significantly alter the peak accelerations of the "head" (p > 0.1) but 10-ounce boxing gloves did significantly reduce the peak acceleration of punches (p < 0.01). In contrast, safety-kick protective footwear resulted in increased peak acceleration values (p < 0.01). It should be noted that there was a difference in the style of kicks to the side of the "head" with and without the protective footwear, as barefoot blows were struck with the ball of the foot and padded kicks were struck with the instep.

Discussion

The analysis of the data in this study was limited to a consideration of peak accelerations. Although there is information about the characteristics of head injuries that are likely to cause injury to the brain, there are relatively few data in the medical literature on the biomechanics of punching and kicking. In general, the punching force of top-performance boxers correlates with body weight. Accelerometers have been hand-aged to the heads of fighters and accelerations up to 100 G have been measured when their opponents wore 6-ounce boxing gloves. Sixteen-ounce boxing gloves reduced peak accelerations to 50 G or less. In the current study, accelerations of 90 G were recorded on several occasions, and one value of 120 G was recorded. This corresponds to the force to which the head of an unrestrained passenger in a low-speed automobile collision might be subjected in striking the dashboard.

Karate-style safety-chop and safety-kick protectors failed to mitigate peak accelerations. With the caveat that kicks to the side of the "head" with and without padding differed slightly in style, it would appear that the karate-style protective hand- and footwear was perceived by the subjects in the study as protection for the wearer rather than for the opponent. The stiffness of the dummy's "neck" was designed to simulate that of a conscious, resisting subject, but Unterharnscheidt has described how a boxer often becomes groggy after a series of blows with the result that there is a decrease in muscle tone of the neck permitting the head to move more like a pendulum at greater rates of acceleration.

Biomechanical studies have generally related to sports where a ball is being kicked, but Feld, et al., developed a simple analysis of the kicking force of karate experts. When kicking a ball, kicks at levels closer to the ground are more powerful. Thus, kicking the head of a falling opponent might be expected to be more dangerous than striking him at the crouching or standing height, especially if he has momentarily lost muscle tone in the nuchal muscles.

Conclusions

In boxing and full-contact karate, blows are frequently directed toward the head; only the means of administering them differ. As a result, one activity cannot be considered in isolation from the other. Violent acceleration of the head by any means produces injury that can now be detected before it is clinically obvious by new neuropsychological techniques based largely on the rate of information processing. Although relatively infrequent but spectacular injuries serve to focus public attention on violent sports, the real issue, in our view, is the insidious progressive damage to virtually all participants and not the deaths in the ring which mercifully affect only a few. We conclude that, if full-contact karate is widely practiced, cases of kickboxer's encephalopathy will soon be reported.